CERN-ACC-2014-0129
Roderik.Bruce@cern.ch

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R. Bruce, A. Marsili, S. Redaelli, CERN, Geneva, Switzerland

Keywords : LHC ; Dispersion Suppressors (DS) ; IR7 ;

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Presented at :
5th International Particle Accelerator Conference, Dresden, Germany
Geneva, Switzerland
June, 2014

CLEANING PERFORMANCE WITH 11T DIPOLES AND LOCAL DISPERSION SUPPRESSOR COLLIMATION AT THE LHC*

R. Bruce†, A. Marsili, S. Redaelli, CERN, Geneva, Switzerland

Abstract

The limiting locations of the present LHC machine in terms of losses on cold magnets are the dispersion suppressors (DS) downstream of the betatron collimation insertion (IR7). These losses are dominated by off-energy protons that have bypassed the upstream secondary collimation system and are lost where the dispersion starts to rise. A solution under consideration for intercepting these losses is the addition of new collimators in the dispersive area. This paper discusses first a proposition for the new layout in the DS, where space is made for the new collimators by replacing an existing dipole by shorter and stronger magnets. Furthermore, simulations with SixTrack are presented, which quantify the gain in cleaning from the new collimators.

INTRODUCTION

The CERN Large Hadron Collider (LHC) [1] is designed to store proton beams at an unprecedented energy of 7 TeV with and a total stored beam energy of about 362 MJ. The HL-LHC upgrade [2] foresees an increase to about 700 MJ. The two beams are guided by superconducting magnets, which risk to quench if just a tiny fraction of the full beam is lost locally. In order to protect the cold magnets, a multi-stage collimation system has been installed [1, 3, 4]. The collimators are mainly installed in the cleaning insertions called IR3 (momentum cleaning) and IR7 (betatron cleaning). They are ordered in a hierarchy, consisting of primaries (TCP, closest to the beam), secondary (TCS) and absorbers (TCLA). The performance of the collimation system is measured in terms of local inefficiency $\eta = N_{\mathrm{loc}}/(N_{\mathrm{tot}}\Delta s)$, where N_{loc} is the number of protons lost locally over a distance Δs, and N_{tot} is the total losses on collimators. In this article, we investigate through simulations how η at the most critical loss locations can be further decreased by adding new collimators.

LAYOUT WITH DS COLLIMATORS

Protons that hit the TCPs may undergo a number of physical reactions. Protons that have undergone single diffractive scattering are often out-scattered again and have often not obtained a large enough angular deviation to reach the downstream TCSs and TCLAs. Instead they have significant energy offsets, which are unimportant in the straight part of IR7, where the dispersion is low, but may cause them to be lost on the aperture in the dispersion suppressor of IR7, where the first bending magnets make the dispersion rise rapidly. In Run I, the IR7 DS was cold location with the highest losses in the ring, and therefore η there limits the maximum allowed beam intensity.

* Research supported by FP7 HiLumi LHC – Grant agreement 284404
† roderik.bruce@cern.ch

One way to decrease the DS losses is to install new collimators, called TCLDs, in the high-dispersion region, upstream of the critical loss location [5]. The proposition in Ref. [5] relies on moving magnets to make space for the TCLDs. In this paper we study another layout, where a standard dipole magnet (8.33 T field) is replaced by two shorter 11 T dipoles [6]. A TCLD is installed in the freed space in between. Therefore, no magnet needs to be moved. Details of the layout and integration are discussed in Ref. [7]. The same concept can also be applied downstream of the experiments in order to mitigate collisional losses during heavy-ion operation [8, 9].

Based on observations of losses and earlier simulation studies [10, 11], we propose a layout where TCLDs are installed in cells 8 and 10 of the IR7 DS. This layout, where two main dipoles have been replaced by magnet-TCLD assemblies, is shown in Fig. 1 together with the dispersion. The TCLDs are installed at 292.4 m and 371.9 m from IP7. These positions differ slightly from the previous study [5].

In order to ensure that the addition of 11 T dipoles does not alter the machine optics, we have studied the optical functions in various layout options using MAD-X. A modular way of replacing any main dipole by the assembly of two 11 T dipoles and a TCLD in MAD-X has been implemented. Using the layout in Fig. 1, it was found that the induced β-beating is below 0.02% and dispersion beating below 2×10^{-4} m in the nominal optics with similar values for ATS. This is significantly smaller than the errors expected due to imperfections. For a full validation of the optics, studies of dynamic aperture should also be performed.

SIXTRACK STUDIES OF CLEANING

In order to assess the gain from the TCLDs, SixTrack [12, 13] simulations have been performed. SixTrack is a multi-turn thin-lens tracking code that has a built-in Monte-Carlo to model the particle-matter interactions in the collimators.

The simulated cases were with no TCLDs, with one TCLD in cell 8 (called TCLD8), or with TCLDs in both cell 8 and cell 10 (the one in cell 10 being called TCLD10). The nominal optics was used since DS collimators might be used earlier than the HL-LHC upgrade. In addition, the local loss distribution in the IR7 DS is very similar between nominal and ATS optics and our results can be applied to both. Some results for ATS optics are shown in Ref. [14].

Both beams, an initial halo in both the horizontal and vertical planes, and two sets of collimator settings (nominal and relaxed) were simulated. The TCLDs were chosen to have the same setting as the TCLAs, which has been verified for impedance and machine protection. All settings are summarized in Table 1. Since the TCLD length could be influenced

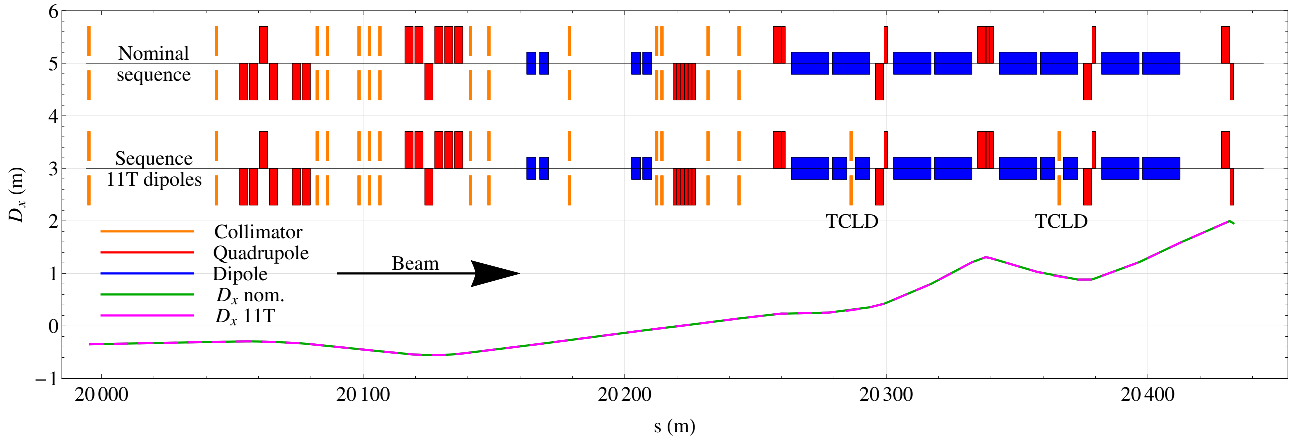

Figure 1: Layout of a part of IR7 with the nominal sequence (top) and with two main dipoles replaced by 11 T dipole assemblies with a TCLD collimator in between (middle). The dispersion function for the two cases, using nominal optics, is also shown.

Table 1: Collimator settings and machine parameters used in the SixTrack simulations. For local losses in IR7, the nominal optics used is very similar to the ATS optics. A normalized emittance of 3.5 μm was used.

Settings	Relaxed	Nominal
E (TeV)	7	7
β^*(cm)	55	55
TCP7 (σ)	7.0	6.0
TCS7 (σ)	10.3	7.0
TCLA7 (σ)	13.0	10.0
TCLD (σ)	13.0	10.0
TCT IR1/5 (σ)	13.2	8.3

by integration constraints, two options were considered for the TCLDs themselves: jaws made of tungsten with a length of 1 m or 80 cm.

As an example of the SixTrack results, Fig. 2 shows the simulated losses for B1 horizontal halo with 0, 1, or 2 TCLDs with nominal collimator settings, both around the ring and zoomed in the IR7 DS. Without TCLDs, the DS losses are grouped in two clusters (cells 8–9 and cells 11-12). As can be seen, the TCLDs provide a very efficient shielding of the DS magnets—depending on the scenario, the TCLD8 reduces the losses in cell 8 by up to a factor 300 and the TCLD10 reduces the losses in cell 11 by up to a factor 500. However, the TCLD8 has a negligible effect on the losses in cell 11 (and, obviously, vice versa), since the momentum cut at TCLD8 is not high enough to shield cell 11, and TCLD10 is downstream of cell 8.

This complementary behavior is further demonstrated in Fig. 3, which shows the integrated losses in the two clusters of the IR7 DS for relaxed settings in B2. For all cases, the TCLD8 has a marginal effect on the losses in cells 11–12 and a large effect on the losses in cells 8–9. As can be seen, the behavior is very similar between horizontal and vertical losses. A qualitatively similar trend, although with better absolute cleaning efficiencies, is observed with nominal collimator settings. Depending on the scenario and setting, the TCLDs decrease the integrated losses by up to a factor 300 in the first loss cluster and up to a factor 500 in the second.

In Fig. 2 it can be seen that the TCLD10 protects not only the cells just downstream, but reduces significantly the losses all around the ring. This qualitative trend is similar for relaxed settings, vertical halo and B2. The fraction of total losses occurring outside collimators goes down by a factor 10–20 for relaxed and nominal settings respectively.

Fig. 3 shows also that the expected integrated losses in cells 8–9 is about a factor 2 higher than in cells 11–12 without TCLD. Cells 8–9 are thus the most critical loss location in the ring. Therefore, the TCLD8 is more important for increasing the LHC performance in terms of the maximum allowed stored intensity, since the it directly decreases the highest cold loss. It reduces also the peak loss over a 10 cm interval in the cold parts of the ring (the highest blue bar in Fig. 2, occurring in cell 8) by about a factor 5–10.

A comparison between the two TCLD lengths is also shown in Fig. 3, in terms of simulated losses in the two clusters in the IR7 DS. It can be seen that there is only a negligible difference between the two cases. This conclusion holds also for the peak loss and the global inefficiency, for the other beam and for nominal collimator settings. From this observation, we conclude that the 80 cm design is the preferred option, since it provides several advantages for the integration. Because of the complementary nature of the TCLDs in shielding losses in the different cells in the IR7 DS, we conclude also that the preferred solution for minimizing the losses in the cold magnets is to install both TCLD8 and TCLD10.

CONCLUSIONS

The limiting loss location in the LHC, with the highest beam losses in a cold magnet, is in the IR7 dispersion sup-

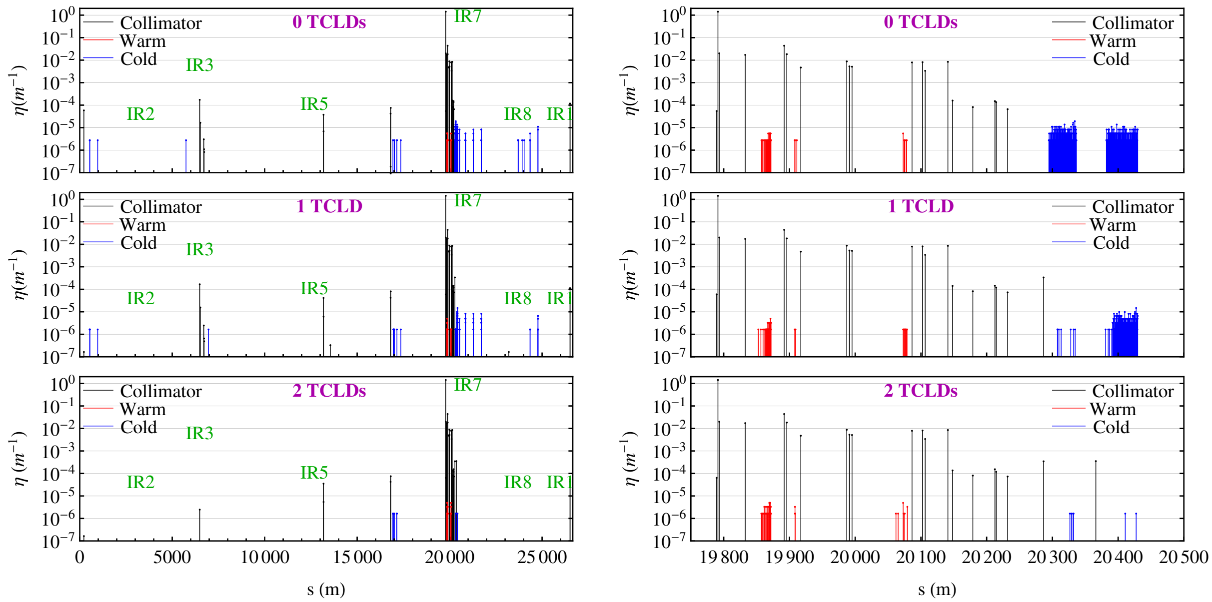

Figure 2: Simulated losses from SixTrack around the ring (left) and with a zoom in IR7 (right) for horizontal losses in B1, using 0, 1, or 2 TCLDs. The TCLD8 is located at $s = 20287$ m and the TCLD10 at $s = 20366$ m. The reduction of nearby losses in the two clusters, as well as direct losses on the TCLDs, can be clearly seen in right part of the figure as the black lines appearing

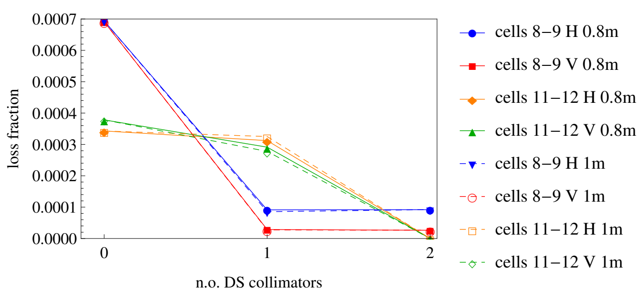

Figure 3: Fraction of losses, simulated with SixTrack, integrated over cells 8–9 and 11–12 in the IR7 DS for relaxed settings, B2, with 0, 1, or 2 TCLDs installed. Results are shown for horizontal (H) and vertical (V) plane, as well as for 80 cm and 1 m TCLD length.

pressor. One very efficient way of reducing the losses there, and thus allow a larger stored beam intensity and a further push of the LHC performance in case of a limitation, is to install additional collimators in the cold region directly in front of the critical locations. An elegant solution from the integration point of view is to replace an existing dipole by an assembly of two shorter but stronger dipoles with a warm collimator in between.

The reduction of beam losses with one or two additional collimators has been assessed through SixTrack simulations, which showed that the peak losses in number of lost protons can decrease by a factor 10–20 and the integrated losses even more. Therefore, it would be very beneficial to install these collimators. However, it is not clear whether the DS losses will actually be the limiting factor in future machine scenarios, since also other factors could constrain the intensity.

In order to further assess the need of DS collimators, additional studies are needed. Firstly, the resulting power deposition inside the superconducting cables has to be estimated quantitatively using e.g. FLUKA in the different scenarios. Results of such a study are presented in Ref. [15]. Furthermore, the collimator settings that can be used could play a significant role. They can not be chosen freely due to constraints coming from impedance and beam stability. If the collimators have to be kept at rather open positions, such as the relaxed settings studied, the efficiency is significantly worse than with nominal settings, which makes the need for the new collimators stronger. We expect that the experience with beam in the LHC run starting in 2015 will answer some of these questions. Therefore, the final assessment of the need for additional collimators probably cannot be made until these data have been gathered.

ACKNOWLEDGMENTS

We would like to thank B. Holzer and M. Schaumann for input on the MAD-X implementation of the 11 T dipoles.

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